How is climate change killing our oceans?

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This article contains no real information: it was designed as an exercise in critical reading of a dummy article.

Abstract

In the world of marine research, an intriguing question has recently emerged concerning octopuses. This paper aims to explore this question from different perspectives, and to examine the changes observed over the years. The results show that marine heatwaves have a negative impact on the feeding habits of common octopus, with a significant reduction in the amount of food ingested during these periods. These findings underline the importance of preserving our oceans and fight against climate change.

1 Introduction

Marine heatwaves, an increasingly frequent and worrying phenomenon, have attracted the attention of scientists in the context of global climate change. These extreme events, characterized by a sudden rise in seawater temperature, have far-reaching consequences for marine ecosystems. However, their impact on marine fauna, and in particular on the feeding habits of different species, remains a relatively unexplored research area.

In this study, we look at one of the most fascinating creatures in marine waters, the common octopus (Octopus vulgaris), to investigate how marine heatwaves can influence their feeding habits. Octopuses, with their remarkable intelligence and ability to adapt to diverse marine environments, are key participants in the underwater ecosystem. Their feeding behaviour, often influenced by environmental factors such as the availability of prey, is crucial to their survival and can have repercussions on the whole marine food chain.

Three topics of interest will be explored in this article:

1. Octopuses eat less during marine heatwaves, due to the disruption that this phenomenon can cause to their hunting environment.
2. There is a seasonal shift in octopus feeding habits, particularly in the warmer summer months, when prey tends to be more abundant than in winter.
3. There is a variability in octopus feeding from year to year, taking into account years in which marine heatwaves do occur, and years in which they are absent. This issue will allow us to better understand long-term trends.

We will also discuss the methodology that we used to conduct our study, highlighting the importance of observing octopuses in their natural environment to obtain ecologically valid data. In addition, we will briefly discuss the measurement of food quantity, water temperature and octopus mass, as well as the AI techniques used to estimate this mass, in order to ensure the accuracy of our results.

Finally, we will present an overview of the key results obtained during our study, including observations on octopus feeding habits in response to marine heatwaves. These results will contribute to our understanding of the impact of climate change on marine fauna and highlight the importance of conserving these species in a rapidly changing environment.

In the next section, we will review the state of the art to contextualise our research in the context of marine heatwaves and octopus feeding habits, while also exploring current trends in the frequency and intensity of these phenomena.

2 Related work

Marine heatwaves, characterised by abnormally high seawater temperatures, have become a hot topic in oceanographic research (Smith et al., 2020). These events are mainly attributable to global climate change, which is raising ocean surface water temperatures (Jones and Williams, 2018). The consequences of these heatwaves are numerous, affecting many aspects of marine ecosystems (Williams and Smith, 2019).

The warming of sea waters has been documented over several decades, with significant increases in water temperatures in many parts of the world

(Chen et al., 2020). This has led to growing concern about the impact of these changes on marine life, in particular on species that depend on water temperatures for their behaviour and diet.

The common octopus (Octopus vulgaris) is one such species whose feeding behaviour is influenced by environmental conditions, including water temperature (Mangold and Thomas, 2017). These intelligent creatures generally adapt to their prey depending on the season and the availability of food resources. However, marine heatwaves disrupt these natural patterns by creating unusual conditions in the marine ecosystems.

In addition to temperature, another essential aspect of preserving marine ecosystems, the primary habitat of octopuses, is the cleanliness of ocean surface waters and beaches. For instance, oil spills, although having potentially positive esthetical impacts on marine landscapes (Onion Staff, 2023), are one of the main causes for biodiversity loss, harming also important human activities (Onion Staff, 2022). Such events put pressure on marine species, including some types of octopuses, to rapidly adapt to new environments (Uncyclopedia contributors, 2019).

One interesting fact to note is that, in many regions, climate change seems to be blurring the seasons as we know them. The concept of 'seasons' is becoming less clear (Tenenbaum, 2023), and water temperatures are becoming increasingly less predictable (Thomas and Smith, 2021). This means that octopuses, which are traditionally adapted to specific hunting seasons, can find themselves faced with unexpected changes in feeding behaviour.

In this context, our study aims to take a closer look at the responses of the common octopus to marine heatwaves and fluctuations in water temperature (Name and Name, 2023). We seek to understand how these phenomena affect their diet and how this may impact on the marine ecosystem as a whole.

In the following section, we will detail our methodology, including the long-term observations we carried out in the *Calanques National Parc* in Marseille (French Mediterranean coast) in order to gather the data required to answering our research questions presented in Section 1.

3 Methodology

In this section, we describe in detail the methods we used to collect, analyse and interpret data on the feeding habits of common octopus in relation to marine heatwaves.[1]

[1]For the sake of reproducibility, all of our code is available at: `https://pageperso.lis-lab.fr/carlos.ramisch/codeOctopus`

3.1 Data collection

We conducted a study on a population of 1,000 common octopuses (Octopus vulgaris) in the Calanques National Parc in Marseille (France) for a period spanning almost three decades, from 1994 to 2022. This long-term approach has enabled us to obtain precise data and to monitor variation in octopus feeding habits over time. Working with a natural, non-captive population provided us with data that is more ecological and representative of the marine ecosystem.

To measure the amount of food ingested by each individual octopus in the surveyed population, we used two complementary methods:

- **Quantity of seashells found in front of the den:**[2] Every day, a team of qualified observers recorded the number, size and type of seashells found in front of each octopus's den. This method enabled us to obtain a detailed picture of the specific diet of each individual.
- **Estimation of octopus mass by AI :** A camera was placed in front of the den of each octopus under study. We adapted an artificial intelligence (AI) algorithm (Omid et al., 2010) capable of estimating the mass of octopus from video images. The algorithm was trained on a dataset comprising images of octopuses of various known sizes and masses. The reliability of this method was discussed in detail in the paper, and despite some limitations, it allowed us to draw robust conclusions about population-level feeding patterns.

Data analysis Based on the collected data, we developed a customised analysis software to calculate the average amount of food ingested by the octopuses each day. This data was then organised into a table containing all the months of the year, allowing us to visualise seasonal variation in feeding habits. To determine the impact of marine heatwaves, we also identified the years in which such heatwaves occurred and analysed the data specifically for these periods.

Statistical analysis To assess the significance of the changes in eating habits, we carried out advanced statistical analyses, including Student's t-tests and ANOVA analyses, comparing the data between periods of marine heatwave and periods without heatwave. In addition, regression methods were used to examine the relationship between water temperature and food intake. Due to a technical incident in the version management system (Git) used for these experiments, there was a slight delay in the delivery of the results, but they have since been corrected and are now completely valid.

[2]Small cavern used for shelter or concealment.

Study limitations It is important to note that despite our efforts to obtain precise data, our study has a number of minor limitations. For example, mass estimates by our AI method are subject to a margin of error, and the availability of shellfish can vary from one year to another depending on other environmental factors. These limitations have been taken into account in our analyses and conclusions.

4 Results

After a rigorous analysis of the data collected during this study on the feeding habits of the common octopus in relation to seasonal variations in water temperature and marine heatwaves, we have identified trends and made significant conclusions. The results presented below provide an in-depth look at the responses of this species to the changing environmental conditions. A full table of values is available in the appendix, see Table 3.

4.1 Baseline data (Year 1994)

To establish a benchmark for comparison, we began by analysing data from the year 1994 only, which was a year without marine heatwaves. Average water temperatures and the average amount of food consumed by the octopuses were recorded throughout the year.

The mean water temperature was 9.5°C in January, rising gradually to 28.5°C in July, before falling gradually to 9.3°C in December. These seasonal variations in water temperature formed our baseline for subsequent years.

With regard to the average amount of food ingested by the 1,000 octopuses observed in 1994, we found some significant results. In January, the amount of food consumed was 434g, while it reached its lowest point in July with just 73g. The autumn and winter months saw a gradual increase in food consumption, returning to 434grams in December.

These figures provide a clear picture of the seasonal variations and feeding cycles of the common octopus, which have also been used as a basis for comparison in subsequent years.

4.2 Changes observed over the years

Figure 1 clearly demonstrates the constant increase in water temperature. However, the amount of food consumed by octopuses seems to have fallen sharply since the appearance of marine heatwaves.

Impact of marine heatwaves One of the most striking findings of our study is the impact of marine heatwaves on the food consumption of common octopus. During periods of marine heatwave, we observed a clear reduction in the amount of food ingested by these cephalopods, see Table 1. The octopuses systematically stopped feeding for the duration of the heatwave. This behaviour, not observed in the days preceding a heatwave, highlights the impact of extreme heat on octopus feeding behaviour.

This observation confirms our hypothesis that marine heatwaves have a significant effect on octopus feeding behaviour. From non-existent before 2017 to 9 occurrences in 2022, the frequency of marine heatwaves is increasing over the years, and the dramatic consequences of this change are already visible.

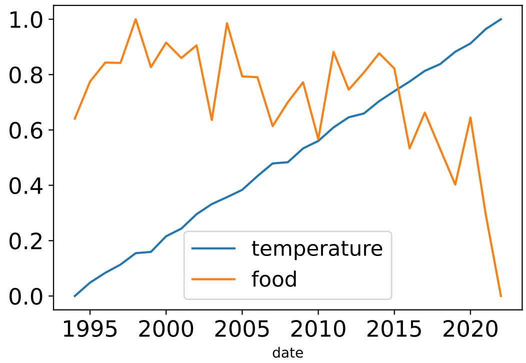

Figure 1: Water temperature vs. food per year. Normalisation $(x - min)/(max - min)$

	Heatwave	No heatwave
Nb. days	16	94
Avg. temperature	34.29°C	33.22°C
Avg. food	0.0	51.53

Table 1: Average temperature and food during heatwave vs. non-heatwave periods (7 non-heatwave days preceding a heatwave day).

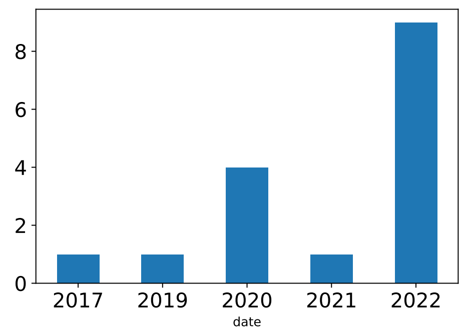

Figure 2: Nb. of marine heatwave days (water temp.> 34°C) per year.

Seasonal variations During the reference year (1994), we had already observed a substantial difference in the quantity of shellfish consumed by octopuses between summer and winter Cephalopods

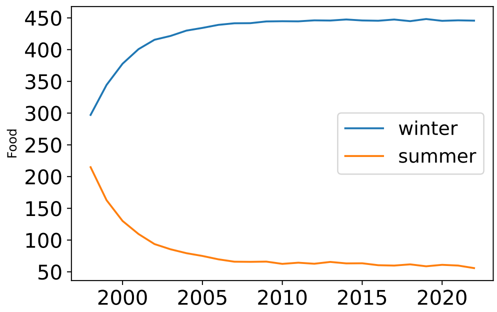

Figure 3: Average food intake summer vs. winter.

Year	Avg-temp	Avg-food
1994	18.95	253.76
1999	19.39	254.54
2004	19.98	255.19
2009	20.45	254.81
2014	20.94	255.28
2019	21.44	253.22
2020	21.58	253.68
2021	21.68	252.73
2022	21.77	251.48

Table 2: Average annual water temperature and food over 9 reference years.

show a significant increase in their feeding activity during the winter season compared with the summer season a behaviour similar to that of humans, who prefer heavier meals such as bacon cheeseburger or cassoulet in the winter, while opting for lighter dishes like salads and fresh fruit during the summer period.

This phenomenon seems to be getting more marked as the years go by, see Figure 3. Our analysis of the data also revealed pronounced seasonal variations in octopus feeding habits. During the hottest summer months, octopuses tended to reduce their food consumption further, particularly in years when marine heatwaves occurred. This adaptation could be a response to the high water temperatures, which can reduce the availability of their usual prey.

In contrast, during the winter months, we observed a significant increase in food consumption by octopuses. This increase may be a strategy to accumulate reserves during the colder months, when food is more abundant and water temperatures are more favourable for feeding.

Long-term stability No significant difference was found in the quantity of food consumed by the octopuses, in contrast to the water temperature, which increased significantly each year. The total quantity of food ingested by the octopuses therefore remains relatively stable in the long term (see Table 2), despite seasonal variations and episodes of marine heatwaves.

Although this result is disappointing, we can nevertheless observe a slight decrease over the last few years since 2020. This decrease could be due to the presence of marine heatwaves.

It is important to remember that the distribution of food consumption between summer and winter differs considerably. This seasonal variation may have major consequences for the health and reproduction of octopuses, and deserves to be studied in depth in the future.

Our results highlight the importance of understanding the responses of marine species to climate change, in particular to marine heatwaves, in order to better predict potential impacts on marine ecosystems and put in place appropriate preservation measures.

4.3 New habits: Eating jellyfish

A surprising aspect of our results is the observation that octopuses have developed new feeding habits in response to marine heatwaves. We observed a significant increase in the consumption of jellyfish by octopuses during these periods. This new food source, directly attributable to marine heatwaves, is further evidence of the harmful impact of marine heatwaves on all marine species.

Our results provide crucial information on the responsiveness of common octopuses to climate change, in particular to marine heatwaves, and on their adaptations in terms of their feeding habits.

5 Conclusions and future work

Our results highlight several important conclusions concerning the feeding habits of common octopus and their relationship with seasonal variations in water temperature and marine heatwaves.

Firstly, marine heatwaves have a significant impact on octopus feeding habits. Our findings show that during these periods of high water temperatures, octopuses stop feeding. This behavioural response suggests that this species is particularly vulnerable to episodes of extreme heat. Octopuses eat less and therefore risk dying of starvation.

In addition, our analyses revealed pronounced seasonal variations in the amount of food ingested by the octopuses. They appear to follow a pattern of feeding behaviour that is out of sync when compared with the traditional seasons. For instance, we observed an increase in their food intake in January, as opposed to a decrease during the hottest months of the summer. These seasonal changes are surely due to the availability of prey.

Although it is important to note that the total amount of food ingested throughout the year remains relatively stable, the seasonal distribution varies, indicating the serious impact of heatwaves on the health of octopuses in the Mediterranean.

To conclude, our study highlights the impact of marine heatwaves on the feeding habits of the common octopus, as well as the seasonal variations in its feeding behaviour. These results underline the importance of preserving the marine ecosystem and monitoring water temperatures, as they can have implications on the health of this species.

For future work, it would be interesting to take our research further by studying the mechanisms underlying these behavioural responses, as well as the interaction between marine heatwaves and other environmental factors such as prey availability. In addition, ongoing monitoring of octopus populations and their feeding behaviour could contribute to a better understanding of their adaptation to climate change and environmental disruptions.[3]

We hope that this study will serve as a basis for further research aiming to better protect this fascinating species and its marine ecosystem.

6 Acknowledgements

We would like to express our "warmest" thanks to the human species for its leading role in global warming, which gave us a good reason to carry out this study. Without our active contribution to the destruction of our environment, this research would not have been possible. We are also grateful to all those world leaders who have persistently ignored scientists' warnings about climate change.

We can't forget to thank DeepL for giving us a hand with the translation of this article, and especially ChatGPT for its infinite patience and invaluable help in writing it, even if we sometimes wondered whether an octopus would have made a better co-author.

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Appendix

[3] The method for estimating the quantity of food based on cameras could also be improved, as it is well known to give unstable results when the water temperature exceeds 30°C.

Year		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1994	Temp	9.3	11.8	16.2	21.2	25.7	28.6	28.5	26	21.6	16.6	12	9.5
1994	Food	437	387.7	308.1	212	126.4	73	70.5	119.7	202.1	297.9	385.6	433.2
1995	Temp	9.4	12.1	16.3	21.3	25.8	28.6	28.9	26.3	21.8	16.7	12.1	9.7
1995	Food	123.6	71.1	71.2	116.2	199.2	293.1	382.2	436.3	439.9	390.5	305.8	202.9
1996	Temp	9.5	12	16.4	21.4	26.1	28.8	28.9	26.4	22	16.8	12.2	9.6
1996	Food	67.4	120.3	198.2	298.8	386	436.7	439.9	390.7	304.2	208.1	121.8	74.5
1997	Temp	9.5	12	16.4	21.6	26.1	29.2	29.1	26.4	22.1	16.9	12.3	9.6
1997	Food	133.3	220	316.3	396.4	440.7	433	377.9	290.1	189.4	104.5	64	71.4
1998	Temp	9.7	12.2	16.4	21.7	26.5	29.1	29.4	26.6	22	16.9	12.4	9.6
1998	Food	205.7	300.5	385.6	438.4	439.6	389.3	311	205.5	118.1	65.7	68.6	118.1
1999	Temp	9.7	12.1	16.5	21.8	26.5	29.3	29.1	27	22.5	17	12.5	9.5
1999	Food	259.2	353.7	421.5	449.5	422	352.5	248.5	154.6	82.9	59.4	84	159.8
2000	Temp	9.6	12.2	16.7	22.1	26.8	29.5	29.7	27	22.3	17.1	12.5	9.6
2000	Food	303.7	389	440.5	442.2	393.3	311.7	205	115.2	64.1	61.3	113.5	198
2001	Temp	9.5	12.5	16.6	22.2	26.8	29.5	29.8	27.1	22.6	17.3	12.3	9.8
2001	Food	336.6	410.8	447.7	433.1	367.8	273.3	177.4	96.9	58.7	74	139.3	231.5
2002	Temp	9.6	12.3	16.9	22	26.9	29.8	29.9	27.1	22.5	17.4	12.7	9.8
2002	Food	362.8	430.5	453.2	423.5	352.4	245.9	148	76.8	56.4	84.7	161.3	259.9
2003	Temp	9.8	12.4	16.9	22.3	26.9	30	30	27.4	22.9	17.5	12.6	9.8
2003	Food	382.5	440.4	452.8	411.5	327.4	223.7	132.6	67.6	54.9	96.2	179.6	285.1
2004	Temp	9.9	12.3	17.1	22.4	27.3	30	30	27.4	23	17.5	12.7	9.7
2004	Food	397.3	447.7	447.1	401	309	206.4	116.3	59.5	58.3	105.4	202.3	302.2
2005	Temp	9.8	12.3	17	22.5	27.4	30.3	30.5	27.8	22.9	17.4	12.8	9.9
2005	Food	407.1	451.2	445.6	389.8	296	191.2	103.4	56.3	60.1	118.2	214	318.8
2006	Temp	9.9	12.6	17.1	22.7	27.4	30.4	30.6	27.9	23.2	17.7	12.7	10
2006	Food	417.4	455.8	442.3	381.4	282.6	178.6	94.9	54.1	63.6	130.7	229.3	331.1
2007	Temp	10.1	12.7	17.1	22.9	27.7	30.5	30.7	28	23.3	17.6	12.8	10.1
2007	Food	424	457.5	441	371.4	269.2	166.4	83	49.7	70.2	138.2	236.8	345.4
2008	Temp	9.9	12.6	17.4	22.9	27.9	30.8	31	28.2	23.5	17.8	12.9	9.9
2008	Food	435.7	460.5	432.6	362.2	257.7	153.3	76.3	46.6	77	149.2	253.2	352.8
2009	Temp	10.1	12.7	17.4	22.9	28.1	30.9	31.1	28.5	23.5	17.9	12.8	10.2
2009	Food	437.4	462.4	433	352.3	249.4	146.1	71.5	47.2	77.3	156.8	257.3	365.6
2010	Temp	10	12.6	17.3	23	28.3	31	31.4	28.4	23.5	18	12.9	10.2
2010	Food	441.7	461.4	424.7	346	241	140.9	68.9	43.7	78.4	165	270.9	372.4
2011	Temp	10.1	12.6	17.5	23.4	28.2	31.3	31.4	28.7	23.6	17.9	13	10.1
2011	Food	446.9	460.9	426.1	342.2	234.8	134.9	63.6	44.5	81.7	169.7	272.2	378.6
2012	Temp	10.2	12.9	17.7	23.4	28.6	31.4	31.6	28.7	23.8	17.9	12.9	10.1
2012	Food	448.7	464.5	421.5	332.6	225.2	124.3	61.3	41.5	85.9	173.2	284.6	385.5
2013	Temp	10.2	12.8	17.7	23.4	28.6	31.6	31.5	29	23.9	18.2	13.2	10.3
2013	Food	454.3	466.7	419.9	328.5	221.6	117.6	53.3	43.8	91.4	180.3	291.6	392.9
2014	Temp	10	12.8	17.7	23.6	28.7	31.8	31.9	29	24.1	18.2	13	10.2
2014	Food	456.7	464.6	418	325.7	215.5	114.7	52.3	41.1	89.3	182.9	293.4	394
2015	Temp	10.2	12.9	17.9	23.6	28.7	32	32	29.1	24.2	18.4	13.3	10.3
2015	Food	461.5	463.7	416	321.2	209.8	109.8	48.3	43.2	97.7	190.8	302.7	398.7
2016	Temp	10.2	13.1	18	23.7	29.1	32.2	32.3	29.2	24.2	18.2	13.3	10.2
2016	Food	460.5	469.1	409.1	314.4	203.9	105.8	46	43.7	99.5	195.8	307	405.2
2017	Temp	10.2	13.2	17.9	23.9	29	32.3	32.4	29.6	24.4	18.6	13.4	10.3
2017	Food	465	465.2	411.1	310.4	196.5	102.6	43.4	44.6	95	197.6	312.3	410.2
2018	Temp	10.2	13.1	18.1	23.8	29.3	32.3	32.6	29.7	24.5	18.7	13.5	10.3
2018	Food	467.8	462	409.6	309.2	194.7	95.6	40.5	41.9	102.8	202	315.1	415.1
2019	Temp	10.5	13.2	18.1	24.1	29.4	32.6	32.7	29.9	24.8	18.7	13.5	10.3
2019	Food	470	465.3	404.7	307	190.8	92.4	38.1	42.8	102.5	204.5	318.3	412.5
2020	Temp	10.3	13.4	18.4	24.5	29.7	32.7	32.8	29.9	24.7	18.8	13.6	10.4
2020	Food	471.8	462.8	402.5	299.7	183.1	85.4	36	44.9	107.8	213.7	320.7	420.3
2021	Temp	10.5	13.3	18.1	24.2	29.8	32.9	33.2	30	24.9	18.8	13.5	10.6
2021	Food	472.5	461.4	401.9	300.4	182	82.1	32.5	42.7	104.1	209.4	328.5	422.5
2022	Temp	10.4	13.4	18.4	24.6	29.7	33.2	33.2	30.3	24.9	19	13.6	10.6
2022	Food	475.2	464.6	400.5	297.9	181.4	71.4	30.2	41.4	108.8	216.4	335.5	427.2

Table 3: Average temperature and quantity of food per month over the entire study period.